PAST AND PRESENT DELAWARE RIVER SHAD FISHERY AND CONSIDERATIONS FOR ITS FUTURE

RESEARCH REPORT 46

FISH AND WILDLIFE SERVICE

UNITED STATES DEPARTMENT OF THE INTERIOR

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PAST AND PRESENT DELAWARE RIVER SHAD FISHERY AND CONSIDERATIONS FOR ITS FUTURE

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ABSTRACT

A study of Delaware River shad was part of an investigation begun by the United States Fish and Wildlife Service in 1950 to supply the Atlantic States Marine Fisheries Commission with information useful in rehabilitating the shad runs of the Atlantic coast. The Delaware River fishery has declined from a peak production of 19 million pounds in 1896 to a level at which it is economically unfeasible for fishermen to operate.

Pollution has had the most severe effect on the runs of shad in recent years, affecting spawners during the upstream migration and both adults and young on their downstream migration. Under present polluted conditions the escapement of young to the sea is dependent upon river flows sufficient to reduce pollution to tolerable levels at the time of migration. Unless pollution is further reduced, even a river flow of 3 billion gallons a day, which has been recommended by the Interstate Commission on the Delaware River Basin, may not be sufficient to provide favorable conditions for shad.

Construction of dams in the Delaware River at Wallpack Bend and at Barryville, N. Y., has been proposed. Present spawning grounds of shad include the entire area above the Delaware Water Gap. To preserve the remnant runs there, and thus make future rehabilitation of the fishery possible, the river below the Water Gap must be kept open for the passage of shad. If dams are built on the main stem of the river, they must be provided with suitable fishways.

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PAST AND PRESENT DELAWARE RIVER SHAD FISHERY AND CONSIDERATIONS FOR ITS FUTURE

The Delaware River was once considered the best shad-producing river along the Atlantic coast. Since the beginning of the 20th century the catch of shad (*Alosa sapidissima*) in this river has been declining, and the run is now in such a critical state of depletion that commercial fishing in the river proper is no longer economically feasible.

Several States and agencies are interested in rehabilitation of the Delaware shad runs. The Interstate Commission on the Delaware River Basin (INCODEL) was established in 1936 by the States of New York, New Jersey, Delaware, and Pennsylvania, to formulate and administer a program for the utilization of the waters of the Delaware River Basin.

The United States Fish and Wildlife Service, acting as the primary research agency of the Atlantic States Marine Fisheries Commission and assisting where possible in the INCODEL program, investigated the Delaware River in 1951 and 1952 to determine the status of the shad runs, the reasons for their decline, and the means by which they can be restored and maintained. The data in this report are the results of that study.

We wish to express our appreciation to the many persons who helped obtain the information presented in this report. Among these are fishermen, sportsmen, and members of various State and municipal agencies.

DESCRIPTION OF THE DELAWARE RIVER

The East and West Branches of the Delaware River originate on the western slopes of the Catskill Mountains. Both branches flow southwesterly until they enter a large valley which descends in a southeasterly direction (fig. 1). South of Hancock, N. Y., these branches join to form the Delaware River at a point approximately 230 river miles above Philadelphia. From this junction the river flows southeasterly to Port Jervis, N. Y. From Port Jervis it flows southerly to Trenton, N. J., where a low natural fall limits the upstream tidal influence. From there the tidal-estuary section of the river flows southwesterly into the upper end of Delaware Bay. The drainage area, covering 12,757 square miles, is inhabited by approximately 5,335,000 people (Interstate Commission on the Delaware River Basin, 1950).

The northern section of the basin above Port Jervis is composed of

heavily forested mountains. Here, the river is comparatively swift and consists of riffles and long pools. The central section of the basin, north to south, is composed of mountains, then of rolling hills, and then, in the vicinity of Trenton, of almost-flat terrain. The gradient of its bed becomes less as the river approaches the tidal estuary.

HISTORY OF THE SHAD FISHERY

Although the shad fishery in the Delaware River dates back to colonial times, the first statistics of production are for the year 1837. Samuel Howell (1837) stated—

> Their average weight may be about 7 pounds, but individuals are occasionally caught which weigh as high as 12 and even 13 pounds.
>
> * * * * *
>
> The aggregate amount taken annually by the shore-seines and the drift-nets is probably not far short of 1,500,000, which, at $7 per 100, would be worth upwards of $100,000.

From this average we can estimate the catch at 10,500,000 pounds. The fishery was evidently well-developed in those early years.

All available figures for the annual catches of shad have been compiled. The combined data on annual production, in pounds, for the parts of Delaware, New Jersey, and Pennsylvania that border on the Delaware River and Bay are given in table 1. Some catches were compiled from publications of the U. S. Bureau of the Census (1911), U. S. Bureau of Fisheries (1904, 1907, 1913, 1923–41), U. S. Fish Commission (1892, 1894, 1901), and U. S. Fish and Wildlife Service (1942–56).

Table 1.—Catch of shad, Delaware River and Bay, 1837–1954

[In thousands of pounds. Statistics from various United States statistical publications listed in text except as noted]

Year	Cach	Year	Catch
1837	10,500	1928 [5]	332
1880 [1]	12,060	1929	461
1887 [1]	11,270	1930	283
1888 [1]	12,389	1931	173
1889 [1]	13,420	1932	182
1890	13,932	1933	172
1891	13,197	1934 [5]	266
1892	10,622	1935	390
1893 [2]	19,000	1936	400
1894 [3]	14,772	1937	243
1895 [4]	16,002	1938	366
1896	19,203	1939	401
1897	14,727	1940	158
1898 [5]	13,932	1941 [5]	186
1901 [5]	13,368	1942	178
1904	5,391	1943	294
1908 [5]	4,462	1944	249
1910 [6]	3,594	1945	238
1913 [5]	3,517	1946 [5]	151
1916 [5]	1,269	1947	157
1917 [5]	883	1948	73
1920 [5]	282	1949	74
1921	178	1950	146
1923 [5]	243	1951	147
1925 [5]	537	1952	128
1926	509	1953	106
1927 [5]	300	1954	76

[1] When the catch was not available for a given year for a given State, an estimate was obtained by determining the ratio of the catches of that State in 1890, 1891, and 1892 to the catches of adjacent States and applying the ratio to the given year's catch of the adjacent States.

[2] Estimated on basis 1896 catch recorded as best since 1893 (Stevenson 1899).

[3] Estimated on basis 1896 catch recorded as 30 percent larger than catch in 1894 (Stevenson 1899).

[4] Estimated on basis 1896 catch recorded as 20 percent larger than catch in 1895 (Stevenson 1899).

[5] When the catch was not listed for a State, the poundage was estimated by applying the ratio of the nearest previous year's catch of the State to catch of adjacent States.

[6] Catch for 1910 and subsequent years for the State of New Jersey (excluding Cape May County catches because the county also borders on the ocean) taken from annual reports of the New Jersey Department of Conservation and Economic Development, the New Jersey Board of Fish and Game Commissioners, and the New Jersey Department of Conservation. These figures are added to the catches listed in various U. S. Government publications for the other two States.

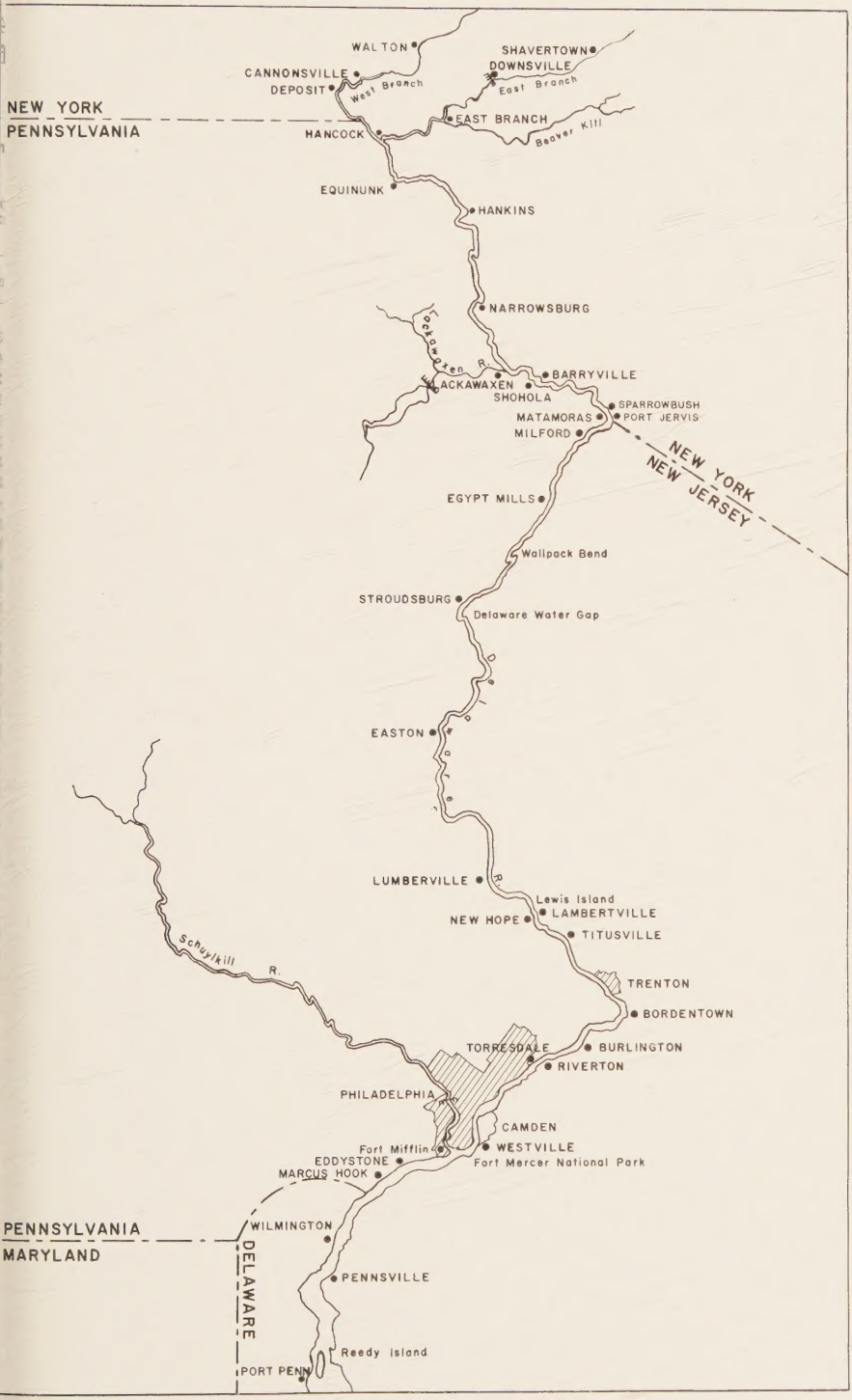

Figure 1.—Delaware River from headwaters to Port Penn, Del.

The figures in table 1 include shad from other Delaware Bay tributaries — shad migrating to other coastal rivers which stray within the lower reaches of Delaware Bay—as well as the shad destined for the Delaware River, because there is no way of separating these groups. In recent years the number of shad destined for other rivers and tributaries and caught in the bay undoubtedly have made up the greater portion of the catches listed. For instance, in 1950 only 22 shad were caught in the Delaware River above Trenton, N. J., and only 35,000 pounds of shad were caught in the estuarine section (Trenton to Port Penn, Del.), while the rest of the 146,000 pounds listed in table 1 was caught in the bay.

Production was at a very high level from 1837 through 1901 in the years for which data are available. The peak year of production was 1896, with 19,203,000 pounds. The catch then began dropping off until by 1920 it was below 300,000 pounds—only a fraction of the big catches of former years. The annual catch fluctuated between 151,000 and 537,000 pounds from 1920 to 1947. The years 1948 through 1954 have the lowest yields on record.

The number of nets of all types used to catch shad in the Delaware River and Bay and the catch of those nets are known for several years (Stevenson 1899; U. S. Fish Commission, 1892 and 1901; U. S. Bureau of Fisheries, 1904–41; and U. S. Fish and Wildlife Service, 1942–56). The drastic changes that have occurred in the number of nets used and the catch per net, betwee 1896 and 1953, are shown in the fo lowing data:

Year	Number of nets	Total catch	Cat per r
		Pounds	*Pou*
1896	1,189	19,203,000	16,
1904	1,145	5,391,000	4,
1910	818	3,594,000	4,
1921	961	178,000	
1930	433	283,000	
1940	256	158,000	
1950	442	146,000	
1951	103	147,000	1,
1952	120	128,000	1,
1953	227	106,000	

In former years, drift gill ne were used in March and April the bay, and as the season pr gressed some of the drift-gill-n fishermen followed the run of sha into the tidal section of the river b tween Port Penn and Trenton. 1896, 259 drift nets placed in Del ware Bay caught 724,677 femal and 374,144 males; below Trento in the river proper, 826 drift ne caught 1,375,561 females and 71 030 males (Stevenson 1899).

Haul seines were used in the est ary, along the entire main river, a up West Branch at least as far Deposit, N. Y. In the section the river below Trenton, 45 sein caught 285,517 females and 231,5 males in 1896 (Stevenson 1899).

The shad fisheries above tid water in the Delaware River, in t early years, were more extensi than on any other river in t United States. In 1896, 176,1 shad were taken in the fresh-wat section of the river. The princip gear fished was the haul seine; seines caught 104,610 females a

4,965 males. Immediately below he Lackawaxen Dam, 30 spears ook 2,160 females and 3,240 males. Only 1 drift net was operated above Trenton and it caught 1,200 shad n 1896 (Stevenson 1899).

The haul-seine fisheries in the resh-water section of the river vere located on long pools (locally alled eddies), where the bottom ould be cleared of obstructions and he seines could be pulled down-tream with the current and onto hallow-water shores. Several fish-rmen cooperated to clear the sein-ng grounds and pull the seines, and he catches were divided among the ishermen or sold locally. Shad ishing was usually limited to April nd May.

Sport fishermen sometimes ormed shad clubs. Such a club was he Binghamton Shad Club, which vas formed by Frank Bowen of Hancock, N. Y., and fished Doyle's Eddy, 2½ miles below Hancock, on Sundays (fig. 2). Bowen's records show that 580 shad were taken in 3 hauls in 1914. The annual catch of the club ranged up to 2,000 shad for a number of years, but the club disbanded because of lack of fish in the area.

Members of the Milford (Pa.) Shad Club reported that their annual catches formerly ranged up to 5,000 fish, but that there was a general decrease until in 1948 they caught less than a dozen shad; consequently, they stopped fishing. They tried seining again in May 1950 but caught only 8 shad.

The decline of the Delaware River shad fishery has brought great economic loss to the fishermen on this river. If catches of shad could be increased to a level comparable to those taken between 1837 and

igure 2.—Binghamton Shad Club haul-seine fishery in May 1905, 2½ miles below Hancock, N. Y. (Photograph furnished by Frank Bowen.)

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1901—which averaged from 10 to 20 million pounds—the income derived, at an average of 20 cents a pound (U. S. Fish and Wildlife Service, 1952), would gross 2 to 4 million dollars annually. At 4-percent interest, an investment of $50,000,000 to $100,000,000 would be required to produce this income. Obviously, the potential capital value of the fishery is great, and the shad fishery would bring large financial benefits to the Delaware River area, if it could be restored.

DISTRIBUTION AND MIGRATIONS OF SHAD

Adult Shad Runs

Before the construction of the dam of the Delaware and Hudson Canal Company, at Lackawaxen, Pa., in the early 1800's, shad migrated regularly to Shavertown, N. Y., on the East Branch of the Delaware, and a short distance above Deposit, N. Y., on the West Branch (Bishop 1935). After construction of the dam the shad were blocked off from the area above Lackawaxen. About 1890, a fishway was constructed over this dam which helped shad reach the headwaters of the Delaware River once again. The Nineteenth Report of the New York State Commission of Fisheries (1890) states that—

> Since the building of the Lackawaxen Dam 45 or 50 years ago, not a shad has been seen above the dam until the spring of 1890, after the fishways were put in, which have proven a great success.

The Delaware and Hudson Canal Company ceased operations near the end of the century and the dam was abandoned. A few years late ice jams tore out the dam and aga the migrating shad had free passa up the river.

Our preliminary survey of t Delaware River in the summer 1950 revealed a very small run adult shad in the fresh-water se tion of the river. As the result an extensive search during the su mer of 1950, we obtained the follo ing information from reports fishermen, State fisheries worke and other interested persons, co cerning the occurrence of adult sh in the various parts of the Delawa River:

Area:	*Period*	*Nu be*
West Branch	July-August	
East Branch	July-August	
Junction of East and West Branches to Barryville	May-July	
Barryville to Wallpack Bend	May	
Wallpack Bend to Trenton	April	
Total		

Of these shad, 24 were taken fro eel racks, 22 were seined, 30 we sighted swimming in shallo eddies, and the carcasses of 17 we found along the river bank. The 93 shad stand in sharp contrast the many thousands that former were caught in this area.

Observations during the spri and summer of 1951 also reveal few adult shad in the river. August, 2 were noted in the Ea Branch, none in the West Branc In the area from the junction of t East and West Branches dow

stream to Barryville, N. Y., 16 shad were seen during June, July, and August. None was seen in the area from Barryville downstream to Wallpack Bend. Below this point and downstream to Trenton, 32 shad were caught during their upstream migration.

In 1952, larger numbers of adult shad were reported in eddies along the Delaware above Trenton than had been observed there for several years. Large numbers were reported by reliable persons to have been seen during July and August in both the East and West Branches, in the Beaverkill (an East Branch tributary), and in the vicinity of Matamoras, Pa., and Lambertville, N. J. (figs. 3 and 4). In former years, most of these observers had fished the Delaware River, and they stated that there were more shad in the river in 1952 than at any time since 1943. Fishermen at Lambertville caught 24 shad in 10 seine hauls during 1 week.

During May 1944, the U. S. Fish and Wildlife Service conducted a survey of the Delaware River to obtain information concerning the deposition of shad eggs. Plankton tows were taken from Bordentown, N. J. (below Trenton), upstream to Equinunk, Pa. (9 miles south of Hancock, N. Y.). The greatest concentration of eggs was found in the area above Lackawaxen, Pa.; no eggs were found below Lumber-

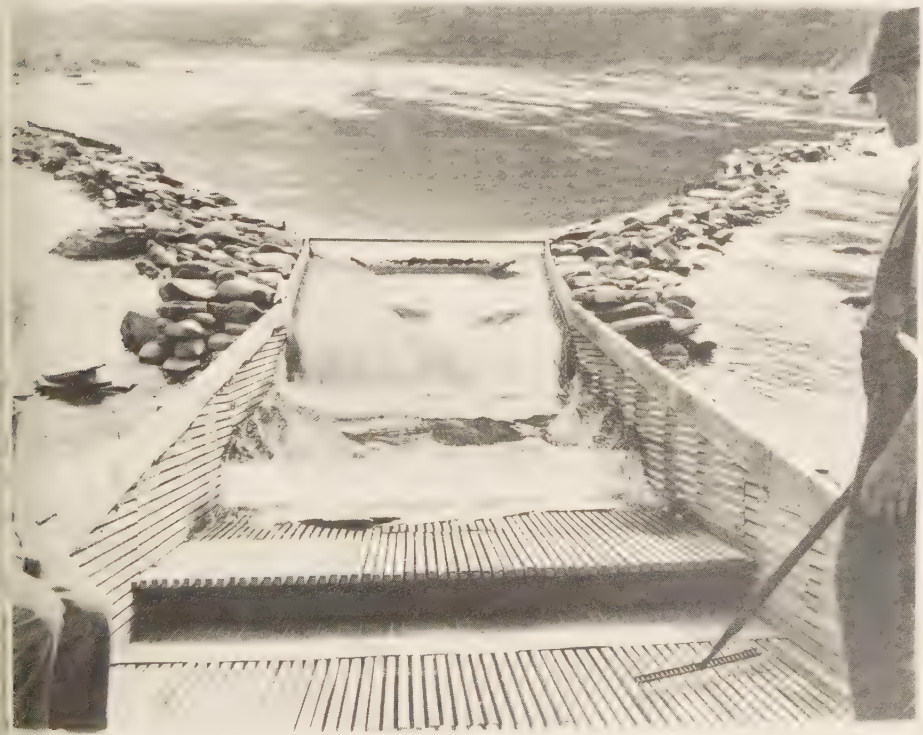

Figure 3.—Upstream view of eel rack on East Branch of Delaware River, showing spawned-out adult shad that were trapped in the rack as they migrated downstream (July 5, 1952). (Photograph by Herbert Buckley.)

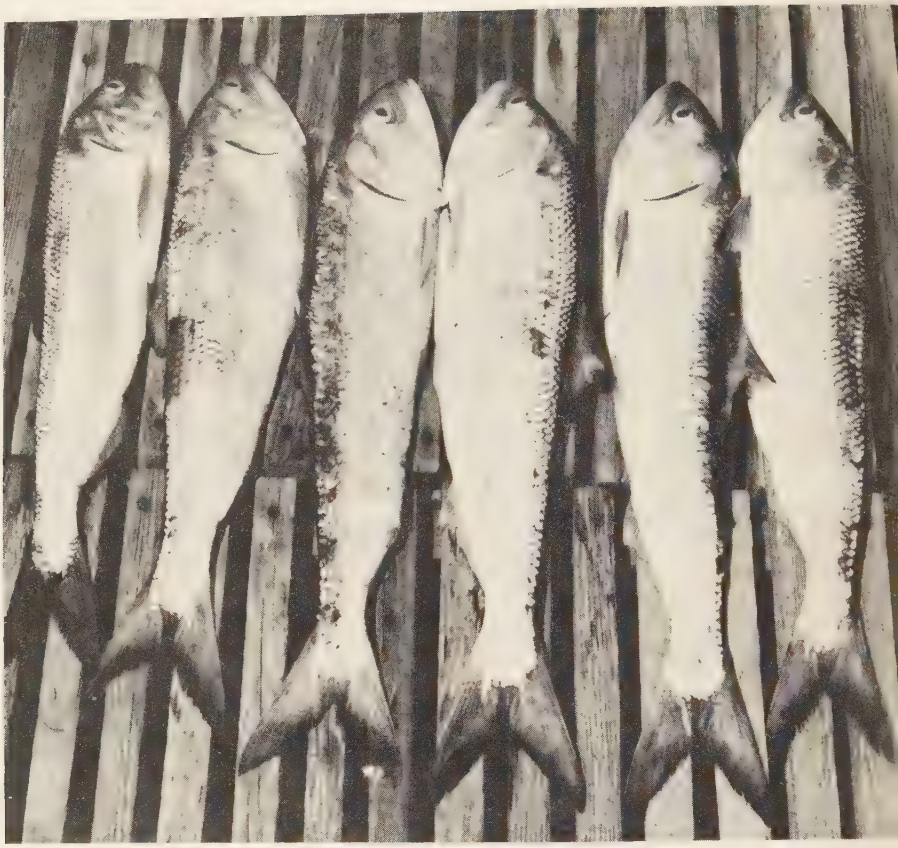

Figure 4.—Closeup view of the six spawned-out shad shown in figure 3. (Photograph by Herbert Buckley.)

ville, Pa. (Cable, unpublished data).

The preceding information indicates that the upper reaches of the Delaware River are being utilized by remnant runs of shad. Catch records of recent and earlier years indicate that the upstream migration takes place during April and May of each year, and surveys of the past few years show that spawned-out adult shad still migrate downstream from the fresh-water section of the Delaware River in July and August, as in earlier years.

Juvenile Shad Runs

In former years, according to local residents, juvenile shad were observed in the long eddies throughout the fresh-water section of the river in numbers so great that their persistent jumping rippled the surface of the water. According to a survey made by the New York State Conservation Department in 1935 (Bishop 1935), young shad were observed in large numbers in the eddy of East Branch opposite Point Mountain near Hancock, N. Y. They were feeding on insects at the

surface, and specimens collected were found to contain flying ants, which were abundant in the area. Juvenile shad were also collected from the Beaverkill during the survey.

Samuel Howell (1837, p. 655) stated—

> The young fish remain in the river until towards autumn, by which time they have attained the size of small herrings, when they in their turn disappear. They are caught in immense numbers in the weirs and racks and baskets which are constructed in the shallow waters above the falls [Trenton] for the purpose of taking the common river fish, and they are so tender as to be destroyed by the least violence. These contrivances, so destructive to the young fish, have consequently become objects of legislative prohibition.

In the Bulletin of the United States Fish Commission, Smiley (1884) stated—

> Thousands [shad] were annually taken between Lackawaxen and Hancock in eel-weirs and bush-seines, the rough and rocky part of the river preventing the drawing of nets. Not only the mature fish were captured, but the young fry were destroyed in immense numbers by hundreds of traps. This indiscriminate slaughter of shad, from the headwaters of the Delaware to tidewater, resulted in their total disappearance from the stream above Milford, and in 1872 the fisheries at that place yielded only single fish where they had once rewarded the fisherman with enormous hauls.

Apparently the destruction of young fish persisted for many years along the river until the enforcement of laws prohibiting the use of the eel basket—a hoop-net of fine mesh with a long bag trailing in the current from the apex of a pair of V-shaped stone walls (fig. 5). Eel racks, however, still operate legally in the river.

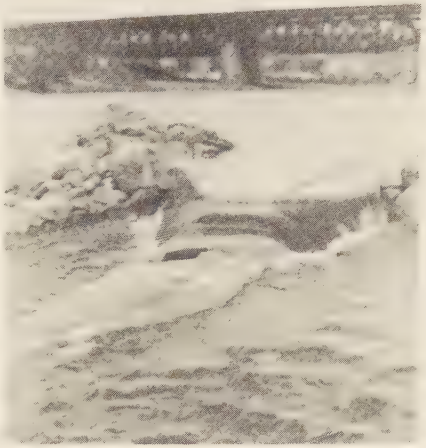

Figure 5.—Upstream view of an illegal eel basket set in the Delaware River below Easton, Pa., September 1930. (Photograph furnished by William Lewis.)

Eel racks, like eel baskets, are constructed in the apex of a V-shaped set of wingwalls. The wingwalls are built with large stones which the fishermen gather from the river bottom. The walls are chinked with grass and small stones, boards, or other material, so that the waterflow from most of the river is funnelled through the rack, which is set between the downstream ends of the two wingwalls. The eel rack is constructed with wooden sides and a sloping floor, all of which are made of slats placed at least half an inch apart. The water flowing through the trap is strained by the slats. The spaces between the slats allow undersized eels and young shad to pass through unharmed. The larger eels are forced by the current up the sloping floor until they drop into a step,

from which they cannot escape (fig. 6). Laws, aimed at preventing the destruction of large numbers of young shad, now govern the spacing of the slats. Eel fishermen say that shovels were kept at the racks in earlier years to clear away the accumulation of young shad when the downstream runs were heavy.

According to eel fishermen interviewed in 1950, seaward migration of young shad is concurrent with that of the eels—beginning some time in September and reaching a peak early in October. In that year, fishermen reported seeing young shad in the eel racks from Hancock, N. Y., on the East Branch, downstream to Easton, Pa.

For the purpose of verifying and defining the distribution of juvenile shad and the time of their migration, in 1951, observers made counts of the young fish passing through the eel racks (fig. 7). Locations and distances of the racks downstream from Deposit, N. Y., were as follows: (1) Deposit, N. Y., on the West Branch; (2) Hancock, N. Y. 11 miles, near mouth of the East Branch; (3) Hankins, N. Y., 30 miles; (4) Narrowsburg, N. Y., 50 miles; (5) Lackawaxen, Pa., 63 miles; (6) Shohola, Pa., 68 miles; (7) Matamoras, Pa., 88 miles; (8) Easton, Pa., 163 miles.

In addition to the counts made at the eel racks, migrating juvenile shad were sampled at a sluiceway through the Union Mill and Paper Company dam at New Hope, Pa. Shad fingerlings have been known

Figure 6.—Downstream view along one of the wingwalls of Ellsworth Bennett's eel rack on the East Branch at Hancock, N. Y., July 5, 1952. (Photograph by Herbert Buckley.)

igure 7.—Counting young shad during the night of Oct. 1, 1951, on an eel rack at Matamoras, Pa.

o come through the sluiceway dur-ng low-water years, when diversion f most of the overflow water is hrough this passage instead of over he dam.

Sampling of the migrating juve-ile shad at the selected eel racks nd in the sluiceway at New Hope ontinued from August 18 through Jovember 5, 1951 (table 2). Since either shad nor eels moved through he racks during daylight hours, ight sampling was necessary. Counts were made on hand-operated allies. Most of the counts of shad er hour listed in table 2 are given n rounded numbers. At times shad ame through the racks in groups f 2 to 10, and precise counts were ifficult to make.

No juvenile shad were taken from he West Branch at Deposit, during he 1951 sampling. Construction of he eel rack at Hancock was completed on August 17, and on August 18 and 19 the operator counted 15 juvenile shad each night (4 shad per hour of counting). No juvenile shad were seen in the East Branch after August 19. According to local fishermen, both juveniles and adults appear at or above Hancock almost every year.

The eel rack at Hankins was fished for eels starting after the middle of September and was first checked for shad fingerlings on September 18. No shad were collected or seen at this station during the remainder of the eel-fishing season in 1951.

Only 2 shad were observed on the eel rack at Narrowsburg: 1 on September 24 and the other on September 27. It appears that any other young shad above this site had moved downriver before sampling began.

A large concentration of shad fingerlings was located in the area between the Narrowsburg and Lackawaxen racks (table 2). Many of them (82 to 900 per hour) were recorded passing through the Lackawaxen rack on October 6, 7, and 8. This heavy run passed through all the sampling racks below Lackawaxen while the river was in flood. During the flood and for some time thereafter (October 8–17) counts were made at the Sparrowbush, N. Y., rack because the Matamoras rack was inaccessible. Inasmuch as the Sparrowbush and Matamoras racks are only 1 mile apart, the number of juvenile shad passing

Table 2.—Location of stations on Delaware River, and dates and counts of migrating juvenile shad per hour, August to November 1951

Date	NEW YORK				PENNSYLVANIA				
	Deposit (West Branch)	Hancock (East Branch)	Hankins	Narrowsburg	Lackawaxen	Shohola	Matamoras	Easton	New Hope
Aug. 18	0	4							
Aug. 19		4							
Sept. 10							5		
Sept. 17					0	0	0		
Sept. 18		0	0	0					
Sept. 19									
Sept. 21					0	0	1		
Sept. 24	0	0	0	1	0	0	0		
Sept. 25					0				
Sept. 26									
Sept. 27	0	0	0	1		1			
Sept. 28					0	3	10		
Sept. 29							20	(1)	
Sept. 30							65	(1)	
Oct. 1		0	0	0		1	59	(1)	
Oct. 2						10		(1)	
Oct. 3	0				0	20		(1)	
Oct. 5	0	0	0	0			0		
Oct. 6					82				
Oct. 7					300	600			
Oct. 8					900	700	2 600	(3)	
Oct. 9	0	0	0	0	(4)	600	2 600	(3)	
Oct. 10						0	2 300	(3)	
Oct. 12	0	0	0	0		0		(3)	
Oct. 13						(4)	2 350	(1)	
Oct. 14							2 350	(1)	
Oct. 15							2 70	(1)	
Oct. 16							2 10		
Oct. 17	0	0	0	0			2 0		
Oct. 18									
Oct. 19							0		
Oct. 22									
Oct. 23	0	0	0	0					
Oct. 25									
Oct. 26									
Oct. 29	0	0	0	0			0		
Nov. 2									
Nov. 5									

[1] No counts made; shad reported seen.
[2] These counts made at Sparrowbush rack; Matamoras rack flooded.
[3] Rack inaccessible because of flood conditions.
[4] Rack washed out by flood.

each of them should be about the same.

The eel rack at Easton was scheduled to be sampled periodically, but access to it was refused; however, some of the men attending this rack reported their observations of young shad during certain periods. These observations are listed in table 2.

During the flood period, the sluiceway at New Hope was fished from October 9 through November 5, but no shad were taken. Since high water occurred this year at the same time as the shad migration, the shad undoubtedly went over the diversion dam at New Hope with the main flow rather than through the sluiceway, which is the usual passage during low water at this time of year.

The movement of young shad possibly was influenced by changes in water temperature. Table 3 lists temperatures and the number of shad counted per hour for each night of sampling on the Matamoras (or Sparrowbush) eel rack. This area of the river was chosen to depict the possible relation between water temperature and rate of movement of young shad, because it was the only area in which shad were moving and could be counted during floodwater stages.

From September 10 through September 24, water temperatures at Matamoras remained at 69° to 70° F., and fewer than 10 juvenile shad per hour were recorded. On September 28, when the temperature dropped from 70° to 68° F., 10 young shad appeared on the rack. On the next night, September 29,

Table 3.—Water temperatures and counts of juvenile shad per hour at Matamoras, Pa., September and October 1951

[Counts made at Sparrowbush, October 8-17]

Date	Water temperature	Number of shad per hour
	°F.	
Sept. 10	69	5
17	69	0
21	69	1
24	70	0
28	68	10
29	65	20
30	58	65
Oct. 1	62	59
5	70	0
8	58	600
9	58	600
10	59	300
13	59	350
14	58	350
15	58	70
16	58	10
17	60	0
19	59	0
29	59	0

the temperature was down to 65°, and 20 shad per hour came through. On September 30 the water temperature was 58°, and 65 young shad per hour appeared. On October 1 the temperature, beginning to climb, reached 62° and 59 shad per hour appeared on the rack. By October 5, the temperature reached 70° and shad had stopped running altogether. When the temperature suddenly dropped to 58° on the night of October 8, the young shad immediately began to run again, and between October 8 and October 16, the remainder of them apparently left this section of the river.

During the 1952 season, various eel-rack fishermen and State personnel checked on the abundance of young shad. No regular counts were made, but shad were observed migrating downstream in the latter part of September and during Oc-

tober in the East and West Branches in greater numbers than had been seen for several years. On the night of October 4, 1952, several thousand young shad were estimated by a member of our staff to have passed through a rack on the East Branch. Large numbers of them were also reported in the middle and lower sections of the Delaware River after their migration from the upper area began.

From the data obtained, it is concluded that the downstream migration of juvenile shad occurs during the months of September and October and seems to be hastened by a lowering of the water temperature, or an increase in water flow, or both. The presence of young shad during the sampling period shows that the entire area above the Delaware Water Gap serves as a nursery and spawning ground. More specifically, the stretch of river above Barryville, N. Y., including the East and West Branches, appears to support the greatest concentration of juvenile shad for the longest period of time. As this area sustains the major portion of the remnant shad runs, it is the most important fresh-water section of the Delaware River.

FACTORS INFLUENCING ABUNDANCE OF SHAD

The causes of the decline in abundance of shad are not known with certainty, but it is believed that some reliable inferences can be made from existing data. During the years between 1837 and 1901 for which figures are available, the annual catch averaged 14,000,000 pounds. After 1901 catches began to decline, and pronounced reductions in take occurred between 1901 and 1904, 1913 and 1916, and 1917 and 1920 (table 1). The causes of these three periods of outstanding reductions in catch are not known. There is a possibility that the overall decline was brought about, at least partly, by overfishing. The decline was perhaps aided by the illegal destruction of young shad in eel baskets and weirs. Nothing is known of fishing rates during these periods, and no factual information is available regarding the numbers of shad destroyed by the baskets and weirs. Consequently, the degree to which the shad runs were affected by these factors cannot be calculated.

Dating back to, and even before, these periods of decline, pollution and the construction of dams were harming the fish. Stevenson (1899, p. 227) stated—

> The Schuylkill formerly yielded many shad. William Penn mentioned in one of his letters that "600 shad had been taken on one sweep of the seine" in that river.

He said further that dams were built across this tributary to the Delaware River and that shad still returned below the dam to spawn until a gas plant was built, and the refuse from it caused the shad to avoid this river.

Pollution in the Delaware River

In 1911 a report of the Commissioner, U. S. Bureau of Fisheries (1913, p. 36) stated—

At various places on the river, but specially in the neighborhood of Philadelphia and Camden, the fishermen complain of the damage done to the shad run by the pollution of the water by city and factory wastes.

Pollution in the Delaware estuary reduces the dissolved-oxygen content of the water (Ellis et al., 1947). The three main pollutants responsible for this reduction are municipal sewage, industrial wastes, and oil. Oil pollution should not exist, since Federal laws prohibit the introduction of oil and oil waste into public waters affected by the tides; but during World War II ships were permitted to flush their bilges in this area rather than at sea because oil slicks could easily be detected by submarines. Oil pollution still is found in the Philadelphia area, but Delaware Bay is reported to be much cleaner.

The following agencies have made various analyses, including oxygen determinations, of water samples from the river:

1. City of Philadelphia Water Department, 1921 to present: Torresdale Intake Station.
2. U. S. Army Engineers, fall of 1938 through 1940: Trenton, N. J., to Reedy Island near the mouth of the river (a distance of 80 miles).
3. U. S. Fish and Wildlife Service, 1946: Delaware estuary.
4. INCODEL, U. S. Geological Survey, and the Departments of Health of New York, New Jersey, and Pennsylvania, July 28, August 16, and September 20, 1949: Various stations along the Delaware River downstream to Morrisville, Pa. (opposite Trenton, N. J.).
5. The Department of Public Works of Philadelphia, August 1949 to present: Industrial section of the Delaware River.

In an effort to determine the relation of water conditions to periods of shad migration and to analyze the effect of low oxygen content on fish life, various data from the agencies listed here were examined and compared. Monthly averages of dissolved oxygen (in parts per million) were obtained from the U. S. Army Engineers for five stations, at Torresdale, Philadelphia-Camden Bridge, Fort Mifflin, Eddystone, and Marcus Hook, for the period October 1938 through December 1940. (This Torresdale sampling station is not to be confused with the Torresdale Intake Station—a separate sampling location used by the Philadelphia Water Department.) For the period August 1949 through November 1952, monthly averages for the same five stations were obtained from the Department of Public Works, Industrial Waste Division, of Philadelphia. The dissolved-oxygen determinations are plotted in figure 8. The monthly average water discharges at the Trenton gauging station (U. S. Geological Survey, 1921–52) are plotted on the graph to illustrate the changes in water quality due to the flushing and diluting action of fresh water entering the industrial section of the river. Since these are monthly averages they do not show daily variations. Figure 8 shows that the dissolved-oxygen content of the water in the area below Torresdale downstream to Marcus Hook falls to zero or near zero during the summer months in all years for which

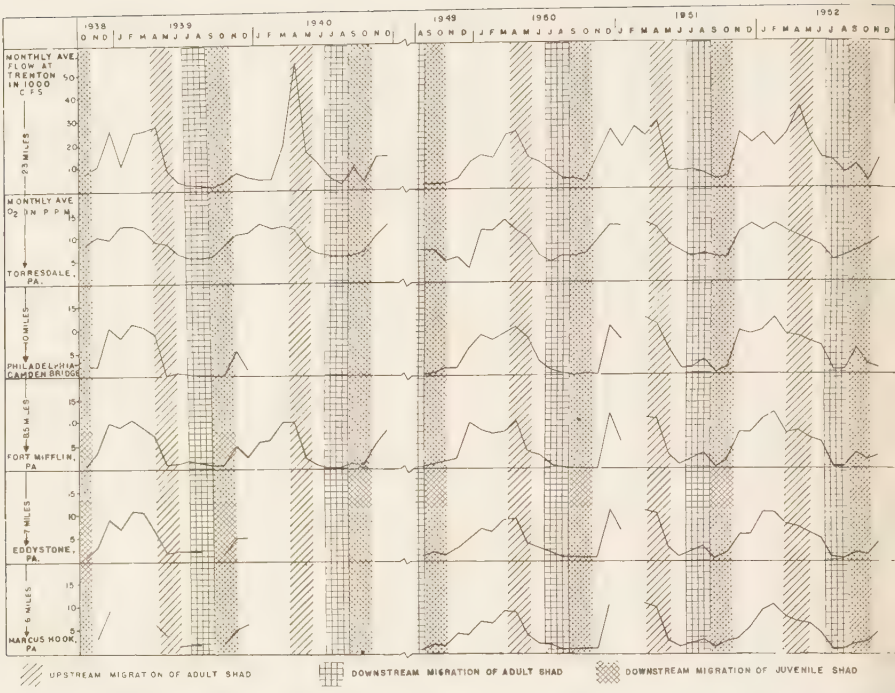

Figure 8.—Monthly average water flow in 1,000 c. f. s. at Trenton, N. J., and monthly average dissolved oxygen in p. p. m. at five stations throughout the industrial section of the Delaware River for various years. Superimposed are the three periods of shad migration: the adult upstream migration, the spawned-out adult downstream migration, and the juvenile downstream migration.

data are available. It is in this area that pollutants are retained by low flows and tidal action, and accumulate to form impassable barriers to migrating fish.

As shown in the listing of agencies that have analyzed the quality of the water in the Delaware River, the only long-term analyses are those made by the Philadelphia Water Department at the Torresdale Intake Station, where the city obtains its drinking water. Records of water quality are available for this station from 1921 to the present time, but since this station is on the upstream fringe of the heavily polluted area the records do not disclose the low oxygen values that occur in the area downstream from it. It was observed, however, that there appeared to be a correlation at low flows in September and October between dissolved oxyen at the Torresdale Intake Station and dissolved oxygen at the next four stations downstream for the years in which records were available. To verify this, table 4 was prepared listing average dissolved oxygen for the four industrial stations, the average for Torresdale Intake Station, and the average river flow for September and October for the years 1939, 1949, 1950, 1951, and 1952. Also shown are the ratios between the average at the four industrial stations and the average at

Table 4.—Effect of river flow on ratio of dissolved oxygen at Torresdale Intake Station and in the industrial section

Month	Average dissolved oxygen		Ratio, industrial section to Torresdale Intake	Average flow
	Four industrial stations	Torresdale Intake		
	P. p. m.	*P. p. m.*	*Percent*	*C. f. s.*
1939:				
September	0.6	6.0	10	1,546
October	1.1	7.3	15	3,567
1949:				
September	0.9	7.0	13	2,719
October	1.4	6.0	23	2,625
1950:				
September	0.9	4.1	22	4,721
October	0.3	5.2	6	3,149
1951:				
September	0.5	5.5	9	4,176
October	1.9	4.9	39	5,528
1952:				
September	4.2	6.4	66	10,040
October	2.5	7.8	32	3,640

Torresdale Intake Station. The ratios and stream flows are shown graphically in figure 9.

It can be seen in table 4 that the ratio of dissolved oxygen in the industrial section to that in the Torresdale Intake Station ranged from 6 to 66 percent. A linear regression and an analysis of variance between the ratios of dissolved oxygen of the two areas and stream flow show a very significant correlation. An F value of 31.29 and an r value of 0.88 ($p<0.01$) imply that as flow increased the ratios increased, indicating that pollution in the industrial section became progressively more diluted. The linear-regression equation for these data is $Y=0.0068X-4.86$. In the formula, X equals

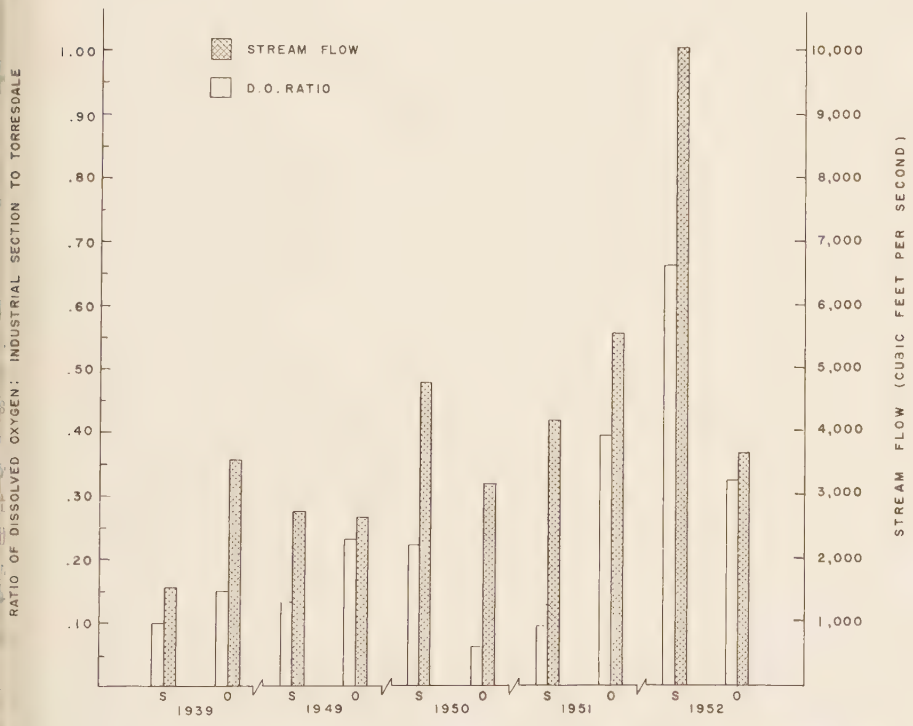

Figure 9.—Ratio of dissolved oxygen in industrial section to dissolved oxygen at Torresdale Intake Station, showing improvement in water quality in industrial section as flow increases, particularly at flows above 5,000 c. f. s.

Table 5.—Average dissolved oxygen for Torresdale Intake (actual) and industrial estuary (estimated) with average Delaware River flow at Trenton, September and October 1921–52

Year	Average river flow at Trenton	Dissolved oxygen	
		Average at Torresdale Intake	Estimated average in industrial estuary
	C. f. s.	*P. p. m.*	*P. p. m.*
1921	3,065	6.6	1.05
1922	3,590	5.7	1.11
1923	3,615	6.1	1.20
1924	9,375	6.7	3.94
1925	5,695	6.1	2.07
1926	8,450	6.5	3.42
1927	17,500	4.6	----
1928	7,410	5.6	2.55
1929	6,010	5.7	2.05
1930	1,925	4.8	0.40
1931	2,260	5.0	0.52
1932	5,820	6.6	2.29
1933	15,264	7.9	----
1934	11,195	7.8	----
1935	3,638	6.2	1.23
1936	3,078	5.8	0.93
1937	8,188	8.0	4.06
1938	13,213	8.6	----
1939	2,556	6.8	[1] (0.85) 0.85
1940	6,754	6.4	2.63
1941	1,634	6.0	0.38
1942	13,990	6.2	----
1943	3,424	4.5	0.83
1944	2,807	4.8	0.68
1945	12,550	7.0	----
1946	4,682	4.0	1.08
1947	3,369	5.7	1.03
1948	2,326	5.4	0.59
1949	2,518	6.4	[1] (1.15) 0.78
1950	3,554	4.7	[1] (0.60) 0.91
1951	4,703	5.4	[1] (1.20) 1.46
1952	7,020	7.1	[1] (3.35) 3.04

[1] Known O_2 averages.

stream flow and Y equals ratio of dissolved oxygen in the industrial area to dissolved oxygen at the Torresdale Intake.

Using the linear-regression equation developed, we can estimate dissolved-oxygen averages in the industrial section of the river for the years since 1921, where water flows were less than 11,000 c. f. s. No flows greater than this were recorded in September and October for years in which dissolved-oxyge averages were available for bot areas. Table 5 shows estimate averages and true averages for th years in which they are available.

Judging from table 5 and figur 8, it appears that in the area fro below Torresdale downstream t Marcus Hook, the period of lo flow, low dissolved-oxygen content and downstream migration of juve nile shad occur simultaneously i September and October.

Effect of Pollution on Shad

In the annual report of the To resdale Hatchery for 1914 (Penn sylvania Department of Fisherie 1914) it was stated that adult sha were very scarce and it was sus pected that the pollution of the De aware River made the water unfi to hatch them. It was stated fu ther that the U. S. Bureau of Fish eries 3 years before had given u the taking of shad spawn becaus of the lack of fish.

The increased pollution of th Delaware estuary has become an im portant and apparently dominan cause of the diminution of fis stocks. In former years the spawn ing grounds of shad extended fro Philadelphia into the upper reache of the river in the State of Ne York, and shad eggs were taken i the vicinity of Philadelphia for a tificial hatching. At present, ex cessive pollution of this section o the river near Philadelphia preven its use by shad as a spawning an nursery area.

From figure 8 and table 5 it evident that the period of juveni downstream migration (Septembe

and October) comes at a critical time as far as quality of the water in the industrial section of the Delaware River is concerned. Heavy mortalities among young shad and herring have been observed during this 2-month's period in recent years and have been reported in and near the industrial section where the water is most seriously affected (Fishing Gazette, 1950). These mortalities undoubtedly were caused by the lethal effects of the low dissolved-oxygen content of the water (table 5) resulting from pollution.

Since 1921, at least, it appears that the successful escapement of young shad through the industrial section has been dependent on a water runoff sufficiently large to dilute and flush the pollutants to safe levels during the migration period.

As shown earlier, the adult shad migrate upstream through the industrial section of the Delaware River during April and May. Sometimes they are hindered by a pollution block at this time (fig. 8) and many die, as was the case in May 1951 (fig. 10). The following is a newspaper account by the Camden Courier-Post dated May 23, 1951:

FISH BRAVE POLLUTION OF DELAWARE BUT PERISH IN NATIONAL PARK AREA

Brum Glutch, operator of the Sanitorium Playground of New Jersey, Inc., located at the foot of Red Bank Avenue, said he first saw a few shad Monday, May 21, 1951, and that they increased in numbers daily.

"But they are running into sure death as they arrive," Glutch said. "They must be hitting contaminated or polluted water not far from here because they are dying almost as quickly as they come up the river."

The downstream migration of spent shad occurs during July and August. Figure 8 shows that this seaward migration is concurrent with a state of low oxygen at most of the industrial stations. Whether this has a significant effect on shad mortality should be disclosed by age analysis of the adults. Scale samples were obtained from shad caught in the Delaware River during 1944, 1945, 1947 (Cable, unpublished data) and 1952. From these scales the age of the fish and the number of times the fish had spawned were determined using the method described by Cating (1953). The age composition and the number of times the shad had spawned were as follows:

Age group	Number of first-time spawners	Number of repeating spawners	Total
3	3		3
4	68		68
5	173	1	174
6	124	4	128
7	44	2	46
8	4		4
Total	416	7	423

Of the 423 scale samples examined, 416, or 98.3 percent, were from shad spawning for the first time, leaving only 7, or 1.7 percent, that had spawned during a previous season. The runs of shad as depicted by these samples are unlike those found in other Middle Atlantic shad rivers, where the populations contain a larger percentage of shad that have spawned during previous seasons. For instance,

Figure 10.—Fish kill on the Delaware River at Fort Mercer National Park, May 23, 1951. (Photograph Camden Courier-Post).

Moss (1946), examining scales from 848 Connecticut River shad, found that 34.6 percent of the fish had spawned previously. Scales from the Hudson River shad examined by Talbot (1955) during the years 1950 and 1951 showed that repeaters made up 51 percent of the runs, and readings of scales from shad taken on Susquehanna Flats, Md., in 1952 showed that 36 percent were repeaters (unpublished data).

A logical assumption is that the number of repeat spawners in the Delaware should be similar to those in other Middle Atlantic rivers. Mortality in the sea would affect shad from other rivers in the same manner as those from the Delaware River. Commercial fishing in the Bay area would take first-year spawners as well as repeaters, and thus would not bring about the low percentage of repeaters in the Delaware River as compared with other streams. Neither would pollution or commercial fishing in the river proper be selective of repeaters over

first-year spawners. In view of these facts, it appears that adult shad have an extremely high mortality rate as they descend the Delaware river on their seaward migration. It is then that they pass through the heavily polluted industrial section and encounter water that is deficient in oxygen.

INCODEL AND SHAD RESTORATION

The Interstate Commission on the Delaware River Basin (INCODEL) has sponsored many developments of conservation including a stream-pollution-control program. As a result of this program more than 300 municipal and industrial waste-treatment plants have been constructed along the Delaware River and its tributaries since 1946.

Because of the ever-increasing demand for water brought about by a rapidly expanding population and industrial development in the lower Delaware River drainage area, it has become one of INCODEL's foremost responsibilities to formulate plans by which the foreseeable water demands may be met. An INCODEL report (1950) states that within the next 30 years it is indicated that the northern New Jersey metropolitan district and the area served by New York City will need an additional 465 million gallons of water daily, and that within a period of another 20 years (1980–2000) the requirements of these areas will probably increase by an equal quantity.

Foremost among the immediate water demands which must be met, as seen by INCODEL, is that of increasing the dry-weather flow in the Delaware River at Trenton, N. J., to a minimum of 3 billion gallons of water (approximately 4,600 cubic feet per second) daily (INCODEL Items, 1952). This would be accomplished by means of storage reservoirs located in the upper Delaware River Basin and would guarantee the minimum 4,600 c. f. s. at Trenton throughout the year. Under present conditions the natural summer flow at Trenton averages approximately 2,300 c. f. s. but often falls below 2,000. It is quite likely that flow maintained at 4,600 c. f. s. will assure a greater survival among future shad runs provided that pollution is adequately diminished. If pollution is not diminished even this flow may not be sufficient to reduce industrial pollution to a degree favorable to fish life.

INCODEL has proposed that two dams (Wallpack Bend and Barryville) be built on the main river and that five dams be built on tributary streams. The two main-stem dams would seriously affect shad production in the Delaware River since they would be located below the spawning and nursery area. Hence, under present water-quality conditions, there would be no suitable spawning or nursery areas left in the entire river. Because of this threat of complete destruction of shad stocks in the river, fishway plans must be included in the projected construction proposals and even their presence would not furnish a complete solution to the problem of shad passage.

Presently, shad are using three fishways in the United States. Two of them are located on the east coast. They are at the Essex Company Dam on the Merrimac River (Collins 1951) and at Holyoke Dam on the Connecticut River. The other is at Bonneville Dam on the west coast's Columbia River (Talbot 1953). At these three dams the differences in elevation between normal pool level and normal tailwater level are 30 feet, 55 feet, and 50 feet. The Interstate Commission on the Delaware River Basin report of August 1950 shows the difference in elevation between normal pool level and normal tailwater level as 95 feet at Wallpack Bend and 73 feet at Barryville. There are no dams of this height over which shad are being passed and, hence, there is no knowledge available as to whether shad would utilize fishways of such heights.

Even though it might be possible to construct fishways that would successfully pass adult shad over the dams as they make their way upstream, little progress has been made in providing safe passage of fish on their downstream migration. A great deal of experimental work has been done in the search for some means of overcoming the hazards to downstream migrants created by dams, but the problems are so involved that satisfactory solution does not seem possible at the present time, particularly where large dams are concerned.

Recent experimental work on survival of downstream migrants as they pass over spillways and through turbines of power dams has shown that many fish die as a result of injuries sustained through abrasions and pressure changes (Hamilton and Andrew, 1954). It therefore appears that even if fishways are provided in the proposed Wallpack Bend and Barryville dams, the number of shad making a successful migration will be reduced. In view of this fact, and in view of the importance of the upper section of the river to shad, consideration should be given to obtaining the desired supply of water by damming tributaries of the Delaware River rather than the main stem. The State of New York has set just such an example by constructing a dam on East Branch of the Delaware River.

SUMMARY AND CONCLUSIONS

In former years, the largest runs of shad on the Atlantic coast were in the Delaware River, and the shad fishery was well-developed during the latter part of the 19th century, with the production well over 19 million pounds in the peak year of 1896. The catch has been in an almost constant state of decline since that time, however, and at present the runs are so reduced that commercial fishing is no longer economically feasible in the river proper. If the shad stocks could be restored to the 1837–1901 levels, at 1952 prices, the fishery would yield some $2,000,000 to $4,000,000 annually to fishermen in the Delaware River area.

During April and May the adult shad move into the upper reaches of the fresh-water section of the

)elaware River on their spawning
ın, and pollution sometimes is
reat enough during this period to
roduce a high rate of mortality.
he spent shad move downstream
uring July and August on their
eturn to the sea at a time when
ollution often blocks their way,
nd heavy mortality again results.

From data collected during this
ırvey, it appears that at present
ıe entire area above the Delaware
Vater Gap constitutes the spawn-
ıg and rearing grounds for the
)elaware River shad and that the
:retch of river above Barryville
ıcluding the East and West
Branches of the Delaware River
ıpports the greatest concentration
f adult and juvenile shad for the
)ngest period of time.

The downstream migration of
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eriod of low flow, low dissolved-
xygen content, and downstream
ıigration of juvenile shad occur
multaneously. In recent years the
s c a p e m e n t of juvenile shad
ırough the estuary appears to de-
end on a water runoff sufficient to
educe the effects of pollution at the
me of migration.

The Interstate Commission on the
)elaware River Basin proposes to develop water resources in the Delaware River to a point where increased water demand from the northern New Jersey and New York City areas can be met. They propose that a system of storage reservoirs be installed in the upper Delaware River basin for this purpose. One of their foremost objectives is to release enough water from the reservoirs to guarantee the maintenance of a daily flow of at least 3 billion g a l l o n s (approximately 4,600 c. f. s.) at Trenton, N. J.

The preservation of the remnant shad population utilizing the upper reaches of the Delaware River watershed depends on keeping this area free from dams that would prevent access to spawning and nursery grounds.

The success of a shad-rehabilitation program on the Delaware River depends on the reduction and continued control of pollution; construction of dams on tributaries rather than on the main stem of the river (or provision of main-stem dams with fishways); and maintenance of a minimum daily flow of 3 billion gallons. This flow could be obtained either from main-stem or tributary dams, provided an appropriate schedule of water releases were maintained. If these objectives are accomplished, there is no apparent reason why the shad runs cannot be rebuilt to their former abundance.

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